Occasional Paper: Using Nature's Own Tool Kit to Clean up the Environment

Summary

Microbes can thrive in the most inhospitable environments on earth, including highly contaminated waste sites, and can even use toxic wastes as sources of food and fuel. In the case of organic wastes, environmental engineers are already using bacteria as chemical factories for cleanup. Recent advances in genomics and proteomics may allow us to use microbes to change the chemical properties of radioactive metals to make them less soluble in water, reducing their ability to migrate and to threaten plants, animals, or human beings.

Microbes have been found living, even thriving, in every conceivable and inhospitable environment on earth—from boiling thermal vents in the depths of the oceans to the ice floes of the artic to some of the most heavily contaminated sites. This remarkable ability of microbes to survive in the most extreme environments can be used to solve some of our most intractable problems, including cleanup of sites contaminated with radionuclides.

The concept of bioremediation is simple: certain microorganisms recognize toxic contaminants as food or energy sources and either consume them outright or make them insoluble in water and thus unavailable to humans, animals, or plants.

Our challenge is to figure out how to get microbes to work for us. The tremendous advances in genomics and proteomics over the last decade will be key to this endeavor. These advances have given us new insights into the workings of biological systems—from an organism's genetic instruction manual, its DNA sequence, to its full repertoire of protein products, the cell's working molecules. Using these advances, we can begin to understand the mechanisms by which microbes survive in the environment—how and what they "eat" and "breathe," how they recognize and travel to sources of food or energy, and how they "socialize" or colonize.

The DOE weapons complex presents some of the most daunting cleanup challenges ever attempted—over 3000 waste sites, 50% of which have soils/sediments or ground-water contaminated with radionuclides or metals. Today's technology of excavation and treatment is not only cost prohibitive, it is frequently ineffective.

The use of methods to cleanup contaminants in place (*in situ* technologies), especially methods that "use" the microbes already living in these contaminated sites, could have a huge impact on our ability to remediate sites in a cost-effective manner.

Bioremediation has already been used effectively for several years to clean up organic contaminants such as oils or solvents. Certain microorganisms recognize these toxic chemicals as "food" and "eat" them. However, radioactive contaminants (a unique problem at DOE waste sites) and metals present another challenge altogether.

Metals and radionuclides cannot be "eaten," i.e., broken down or converted into entirely different chemical forms, by microbes or even by harsh chemical treatments. But microbes can change the chemical properties and thus the solubility of metals and radionuclides in water causing them to precipitate as solids in their underground locations, thereby reducing their availability to humans, animals, or plants, and making them effectively nontoxic.

For this reason, the Office of Science's Natural and Accelerated Bioremediation Research (NABIR) program focuses on understanding the capabilities of microbes that could be used to control the movement of metal and radionuclide contaminants. As noted above, microbes that occur naturally at contaminated sites are often able to cause these decontaminating transformations of metals and radionuclides. Thus, the focus of the NABIR program is on native microbes, what they can already do on their own, and what we can do to stimulate them (possibly by adding additional nutrients) to clean up the surrounding metals and radionuclides.

It is important to remember that microbes can only contain the contaminating metals and radionuclides by making them insoluble in water, but these contaminants are not destroyed. This presents several scientific and social challenges. How can we be sure that these contaminants won't be reconverted from an insoluble to a soluble form at some time in the future—10 years, 100 years, 1000 years—and then become a health risk again? This is not only a technical issue but a social one as well and the NABIR program is addressing both.

The NABIR program supports a broad range of fundamental scientific research aimed at making bioremediation an efficient, safe, and cost-effective reality. Examples of issues being addressed in DOE's NABIR program include:

- understanding the genes, gene products, and genetic regulatory networks that enable microbes to convert metals and radionuclides into safe, insoluble forms.
- understanding the mechanisms by which microbes make these conversions.
- understanding the roles of individual microbes versus complex microbial communities in contaminant detoxification.
- characterizing the range of contaminants—especially, radionuclides—recognized by microbes as "food."
- determining the physical and chemical types of soils and sediments in which bioremediation can be effective.
- understanding the effects of added nutrients on the ability and efficiency of microbes to detoxify metals and radionuclides.
- determining the long-term stability of precipitated metals or radionuclides in the environment.
- understanding public acceptance of or concerns for bioremediation as a safe and cost-effective cleanup strategy.

NABIR research is intricately linked to ongoing DOE research in genomics, structural biology, and microbial biochemistry. It also relies heavily on DOE cleanup research in the Environmental Management Science Program (EMSP), which the FY 2003 budget proposes to move from the Office of Environmental Management to the Office of Science, a move that would complement and "complete" the goals of the NABIR program.

EMSP focuses on characterizing the forms and movement of contaminants in the subsurface at DOE sites. It develops technologies needed for the long-term monitoring of these contaminants, strategies for long-term stewardship of waste sites, and models that can be used to predict the movement of contaminants in the subsurface environment.

Another piece of the bioremediation research puzzle is the Environmental Molecular Sciences Laboratory (EMSL), one of DOE's newest national scientific user facilities, located at Pacific Northwest National Laboratory. EMSL provides cutting-edge molecular tools needed to develop a molecular and cellular level understanding of the challenges and possibilities of bioremediation—from microbial genetics and cellular interactions to characterization of field samples and subsurface transport modeling.

In the end, the success of bioremediation in the DOE complex will have much broader impacts than "simply" providing a cost-effective alternative to "pump and treat" methods of remediating waste sites. These new tools will be used to remediate for mining and industrial wastes around the world, as well as for new purposes, such as selective separations of metals.

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